BALLISTIC PENETRATION OF ZYLON SHEETS

The cooperative contract 01-C-AW-UCB between the University of California, Berkeley, and the FAA is concerned with an experimental and an analytical investigation of the perforation resistance of Zylon sheets upon disintegrating metallic fragment impact. This work is supervised by Principal Investigator, Werner Goldsmith, Professor of the Graduate School, UCB and Tarek Zohdi, Asst. Professor of Mechanical Engineering. SRI, represented by Dr. Don Shockey, and Boeing Co., represented by Dr. Jerry Farstad, are subcontractors. This report is concerned solely with the activities at Berkeley, representing small-sized fragments. The activities of SRI, concerned with analytical and experimental investigations of larger fragment simulators, and that of Boeing, directed towards the determination of the mechanical properties of this polymeric fiber, including environmental factors, is to be reported separately. The Zylon fibers are produced by Toyobo Corporation and the sheets are woven in the United States.

The experimental work at Berkeley, executed by Mr. Kelvin Kwong, an M.S. student, is performed by means of a powder gun which fires hard-steel projectiles at a collection of adjacent Zylon sheets at velocities in the vicinity of 150 m/s (450 ft/s) that will be increased to 450 m/s (100 ft/s) in the future. The striker consists of a copper-coated plane-ended cylinder of 12.7 mm (1/2 in) diameter with a length of 38.1 mm (1.5 in). Initial velocities are measured by the signal recorded on a time-interval meter due to the interruption of two parallel laser beams, a fixed distance apart, that are focused on a pair of photodiodes. The 13 x 13 in. targets, which feature 35 x 35 fibers per square inch, are clamped in a steel frame with an interior opening of 10 x 10 in. by means of a set of bolts pre-tensioned in place by a torque wrench. Final velocities are measured by either one or several of the following devices: (a) a digital video camera recording up to 10,000 fr/s, (b) a set of make-grids approximately 50.8 mm (2 in) apart whose completed circuit is recorded by a time-interval meter upon contact by the projectile, or a similar set of two pairs of aluminum foils, with each pair closely spaced. Approximately 25 experiments have been conducted to date in the velocity range from 120-160 m/s, with impact initially randomly located, but lately concentrated at the center where the fewest sheets (approximately 6) are required to stop the projectile; at impact points near the corner, either 8 or 10 sheets are needed to achieve the same result. There is no deformation of the striker due to the impact.

The location of the impact is critical concerning the ballistic limit, due both to differences in individual fiber stretch and deformation of the sheet as a whole, which absorb differing amounts of energy and hence affect penetrability. Currently, the ballistic limit of 6 sheets has been determined to be about 150 m/s for central impact, whereas impact near a corner requires a greater amount of fabric. It is intended to complete 6 and 8 and perhaps 10-sheet ballistic limit shots, then proceed to impacts halfway from the center to the corner, and to repeat these shots for Kevlar which will require a larger number of sheets for the ballistic limit at this speed due to its lower penetration resistance.

It is anticipated that the experimental program will include suspension of the sheets on only two opposite sides, and also suspension from pegs. Higher initial velocities will be conducted when the 150 m/s sequence is completed.

A finite element numerical scheme has been developed by Prof. Zohdi and a graduate student, Mr. Li, to simulate the experimental program, employing their own codes. The impact conditions are those of the tests conducted. The codes include consideration of the uncertainties from yarn to yarn of the microscale misalignment of the fibers comprising such bundles. These effects are included in the large-scale simulations in order to ascertain the macroscopic response, with particular reference to the number of sheets required to stop the projectile at a given speed and impact position. Since the deformations of the fabric are finite and nonlinearly inelastic due to progressive inhomogeneous micro-fiber rupture within the yarns, which lead to noisy degradation and, further, to dynamic coupling to the projectile, the system is highly nonlinear. The effects of this noise, which can be bounded by a constitutive tube of uncertainty, are important in ascertaining the limits of what be determined in actual laboratory experiments.

A temporally adaptive, iterative fixed-point scheme has been developed to solve the stochastic system by extending previously developed methods for deterministic systems. Some large-scale 3-D numerical examples have been computed to illustrate the approach in determining the number of sheets needed to stop a projectile, as well as scatter in the results. The number of sheets has been determined as approximately 9 for the present conditions. A second code is currently being examined to ascertain whether it conforms to the initial code and to experimental conditions.

Werner Goldsmith
Tarek Zohdi